

Feasibility of a Negative Pressure System to Remove Smoke from an Aircraft

Flight Deck

by

Russell Davies

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science in Technology

Approved November 2013 by the
Graduate Supervisory Committee:

Bradley Rogers, Chair
Dale Palmgren
John Rajadas

ARIZONA STATE UNIVERSITY

December 2013

ABSTRACT

Smoke entering a flight deck cabin has been an issue for commercial aircraft for many years. The issue for a flight crew is how to mitigate the smoke so that they can safely fly the aircraft. For this thesis, the feasibility of having a Negative Pressure System that utilizes the cabin altitude pressure and outside altitude pressure to remove smoke from a flight deck was studied. Existing procedures for flight crews call for a descent down to a safe level for depressurizing the aircraft before taking further action. This process takes crucial time that is critical to the flight crew's ability to keep aware of the situation. This process involves a flight crews coordination and fast thinking to manually take control of the aircraft; which has become increasing more difficult due to the advancements in aircraft automation. Unfortunately this is the only accepted procedure that is used by a flight crew.

Other products merely displace the smoke. This displacement is after the time it takes for the flight crew to set up the smoke displacement unit with no guarantee that a flight crew will be able to see or use all of the aircrafts controls.

The Negative Pressure System will work automatically and not only use similar components already found on the aircraft, but work in conjunction with the smoke detection system and pressurization system so smoke removal can begin without having to descend down to a lower altitude. In order for this system to work correctly many factors must be taken into consideration. The size of a flight deck varies from aircraft to aircraft, therefore the ability for the system to efficiently remove smoke from an aircraft is taken into consideration. For the system to be feasible on an aircraft the cost and

weight must be taken into consideration as the added fuel consumption due to weight of the system may be the limiting factor for installing such a system on commercial aircraft.

DEDICATION

I would like to dedicate my Masters Thesis to my parents Ann and Barry as well as my brothers Jon and Graham.

My father Barry, who's spent 40 years working as an Electrical Engineer, has taught and guided me through my schooling and career. My mother Ann, along with my father, have both provided me with encouragement and support.

My Brothers Jon, an ASU Mechanical Engineering Technology student, and Graham, an ASU Chemical Engineering Alum, have both supported and challenged me with their knowledge to help push me forward to better myself.

ACKNOWLEDGMENTS

I would like to thank all the Professors and faculty at ASU who have helped guide me throughout my undergraduate and graduate studies in Mechanical Engineering Technology to help get me to this point. Special thanks to Dr. Rogers for encouragement and advice as an undergrad to get me into the graduate program and subsequent guidance to help me complete my thesis. I would also like to thank Dr. Rajadas and Dr. Palmgren for their time, effort, and enthusiasm to be my committee members.

Lastly, I would like to thank all those I work with directly at US Airways and indirectly through US Airways repair vendors and OEM suppliers. They have taught me a great deal about the industry and aircraft systems. It is this knowledge I was taught through work experience that I was able to develop this thesis topic.

TABLE OF CONTENTS

	Page
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF ACRONYMS	viii
CHAPTER	
1 INTRODUCTION	1
2 LITERATURE REVIEW	4
3 METHODOLOGY	12
4 RESULTS	19
5 CONCLUSIONS & RECOMMENDATIONS	23
REFERENCES	25
APPENDIX	
A BOEING 737-700/800 QUICK REFERENCE HANDBOOK (QRH) SMOKE/FUME REMOVAL PROCEDURE	28

LIST OF TABLES

Table	Page
1 Time of Useful Consciousness vs. Altitude.....	19

LIST OF FIGURES

Figure	Page
1 Boeing Study of Smoke Events.....	2
2 FAA 20 Year Passenger Forecast	3
3 Fatal Airline Accidents	5
4 O2 Mask Types	6
5 IVU Removed from Container and Placed in Front of Captain	8
6 IVU Inflated to View Critical Flight Instruments	8
7 Pilots Using IVU	9
8 Typical Aircraft Pressurization System Schematic	13
9 Aircraft Pressurized Areas	13
10 Cabin Altitude vs. Airplane Altitude	15
11 Negative Pressure System Layout	18
12 QRH 737-700/800 Smoke Removal Procedure	29

LIST OF ACRONYMS

Acronym	Page
NTSB National Transportation Safety Board	2
FAA Federal Aviation Administration	2
InFO Information for Operators	4
EVAS Emergency Vision Assurance System	7
IVU Inflatable Vision Unit	7
QRH Quick Reference Handbook	10
AC Advisory Circular	10
CFR Code of Federal Regulations	10
ASD Aspirating Smoke Detector	14
FAR Federal Aviation Regulation	16
CAQ Cabin Air Quality	17
EDS Energy-Dispersive Spectrometer	17
SEM Scanning Electron Microscope	18

CHAPTER 1

INTRODUCTION

Since the beginning of aircraft passenger travel, the aviation industry has made much advancement in aircraft safety and reliability helping to ensure the flying public a safe arrival to their destination if they so choose to travel by air. The advancement in aviation safety has come from improved reliability of mechanical systems and also improved avionics. The avionics of a modern aircraft have made the aircraft virtually fully automated with airline pilots tending to only be manually flying the aircraft 90 seconds during take-off and 90 seconds during landing with the majority of flight being controlled by automation. This automation has said to have diminished an airline pilot's skill and ability to make split second decisions to safely fly an airplane which has led to the loss of control of an aircraft with catastrophic results [1]. Furthermore, the more avionics installed on an aircraft increases the potential for an electronics fire.

Between November of 1992 and June of 2000, Boeing did a study showing that the majority of events that resulted in smoke entering the aircraft were a result of electronic system failures [2]. Figure 1 shows Boeing aircraft, listed in order of avionics complexity, with the percentage of smoke events due to Electronic failures compared to smoke from the air conditioning system and smoke caused by other materials. The air conditioning smoke events were where smoke passed through the air conditioning ducts. The smoke may have originated as a result of an event such as engine oil burning. Materials smoke refers to items such as a coffee machine or an oven malfunction that produced smoke.



Figure 1: Boeing Study of Smoke Events [2]

With the increases in automation, the avionics becomes a source of smoke and fire. In part, due to this fire risk, the National Transportation Safety Board (NTSB) in November of 2012 published their “Most Wanted List” with Improving Fire Safety in Transportation as one of their top 10 issues [3]. One of the reasons to tackle the issue of Fire Safety is that the Federal Aviation Administration (FAA) published their 20 year Aerospace Forecast for Fiscal Years 2012-2032. The FAA study estimates that close to 500 million more passengers will fly annually by 2032 than in 2012 as depicted in Figure 2 below [4]. Airlines will have to compensate the increase in passengers with more aircraft, thus increasing the potential for a smoke related event.

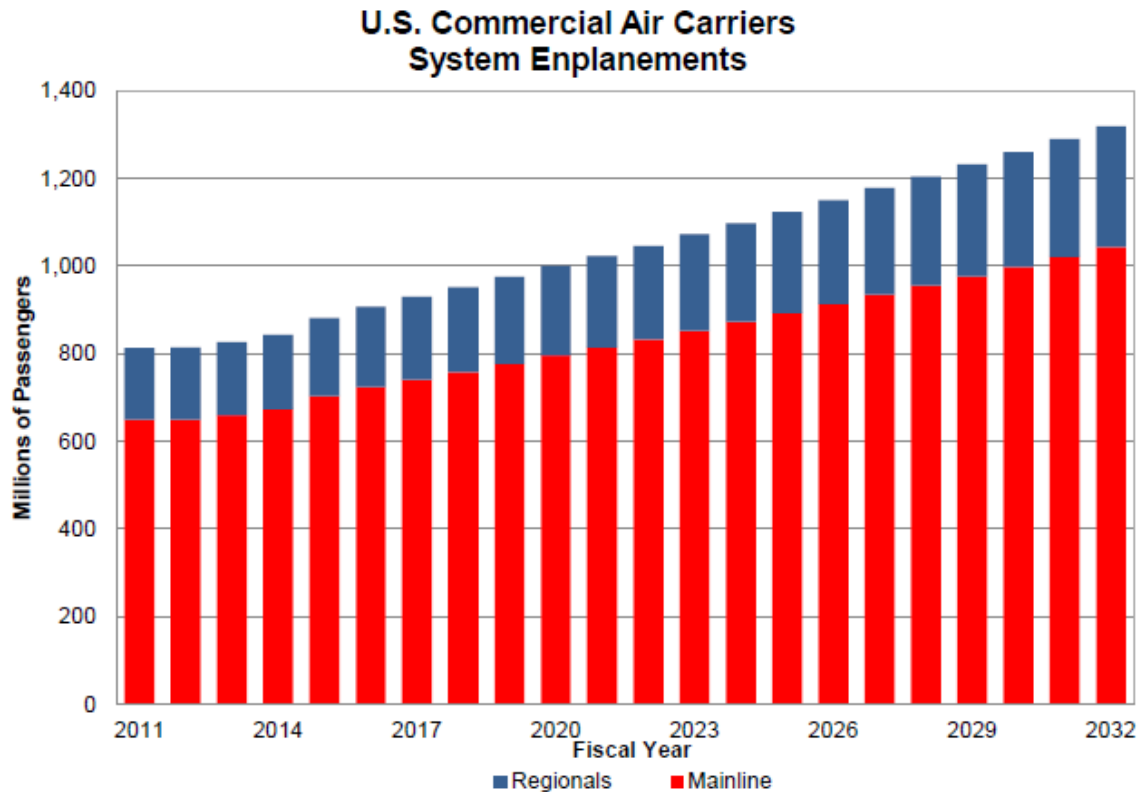


Figure 2: FAA 20 Year Passenger Forecast [4]

With the increase in amount of electrical equipment for automating the aircraft, which in turn diminishes the pilot’s quick thinking ability, more aircraft flying, and the NTSB’s push for Improving Fire Safety, there is a need to effectively remove smoke from a flight deck. In doing so, the pilots can more easily stay calm and focused without trying to view the aircraft instrumentation through a smoke filled flight deck. This research will look at utilizing the pressure difference between the cabin and atmosphere at cruising altitude to determine the feasibility of using a negative pressure system to remove smoke from a flight deck.

CHAPTER 2

LITERATURE REVIEW

With advancements in avionics there is a potential for electrical failure such as that of the Japan Airlines Boeing 787 at Boston's Logan International Airport in January of 2013; which was one of several events on the 787 that lead to the grounding of the fleet by government officials [5]. This event however occurred while the aircraft was on the ground and empty of passengers and crew. In many cases though, smoke events occur while the aircraft is in flight which presents serious risk and danger to the passengers and crew. In October of 2010, the FAA released an Information for Operators (InFO) asking operators that experience a smoke or fumes event to collect the data for the FAA so it can be tracked and determine trends. This is due to the fact that the FAA Office of Accident Investigation and Prevention receives over 900 reports a year on smoke or fumes in the cabin and or cockpit. The InFO stated that in a single day in April of 2010, five aircraft had emergencies declared and diverted to the nearest airport due to smoke or fumes [6]. Though the vast majority of reported events have no further incident, tragically, smoke in the cockpit has been a cause of fatal aircraft crashes. In Figure 3 below from Boeings Statistical Summary of Commercial Jet Airplane Accidents, there were 2 fatal accidents resulting in 4 losses of life between the years 2002 and 2011 [7].

Fatal Accidents – Worldwide Commercial Jet Fleet – 2002 Through 2011

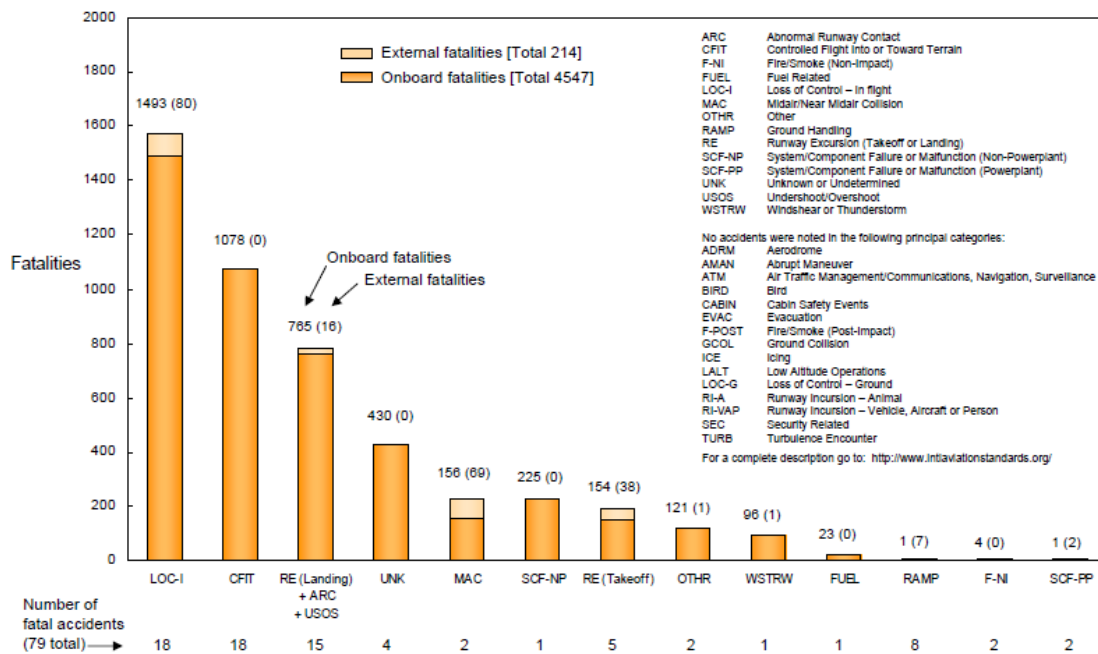


Figure 3: Fatal Airline Accidents [7]

One of the two aforementioned accidents was a UPS 747-400 Freighter that took off from Dubai and reported smoke in the flight deck less than a half-hour after takeoff. The crew attempted to return to Dubai and declared an emergency. Reports of the accident indicated that the Captain had control of the aircraft but due to the smoke, could not see critical flight instruments nor able to properly tune the radio frequencies for the airport. Due to inability to see the critical instruments, the aircraft was too high for landing at the airport and passed over the runway. The aircraft made a turn to the right and crashed [8].

Shortly after the UPS 747-400 accident, the NTSB released a Safety Recommendation after determining the Oxygen Masks used by the flight crew was a contributing factor. The masks come in two forms: 1) Oxygen Mask with separate goggles similar to the UPS Crew and 2.) A full face mask (Figure 4 below).



Figure 4: O2 Mask Types. Goggle and Mask (Left) Full face (Right) [9]

The NTSB provided reason that the separate goggle and mask type prove difficult to put on. The goggles do not always seal tightly causing smoke to enter the mask (or vent in if the vent is not properly closed) and communication becomes difficult. The Safety Recommendation from the NTSB said the Oxygen masks have two purposes (selected by a valve switch on the mask), to 1, provide supplemental diluted oxygen with ambient air depending on pressure altitude in the event of depressurization and 2, the mask has a switch that can be selected to provide 100% oxygen in the event of smoke or fire [9]. From the NTSB report, the goggles merely prevent smoke from irritating the eyes but they do not improve vision in the smoke.

From Boeing Aero14, Boeing conducted a review of fire events that resulted in hull loss indicates that the time from first indication of smoke to an out-of-control situation may be very short — a matter of minutes [2]. This is in part due to the fact that smoke not only can prevent seeing critical systems as in the case with the UPS accident, but the smoke can lead to smoke inhalation if the Oxygen mask is not immediately used. If oxygen amounts are normal in the flight deck compared to standard air, at about 21%, oxygen levels only have to drop to 17% before impaired judgment and coordination [10].

This smoke then in turn may lead to Spatial Disorientation which is the mistaken perception of one's position and motion relative to the earth. Any condition that deprives the pilots natural, visual references to maintain orientation can rapidly cause Spatial Disorientation [11].

With the immediate danger that smoke presents an aircraft crew, there is a need for a system to remove smoke from an aircraft flight deck. One such technology already exists; which is a smoke displacement technology known as Emergency Vision Assurance System (EVAS). This device is currently the only smoke displacement technology enabling the pilots to see through the smoke [12]. The EVAS System is an inflatable balloon like device, known as an Inflatable Vision Unit (IVU) that displaces flight deck smoke by taking up the volume of space in the flight deck. When inflated there is a viewing window on either end of the IVU with the intent that the flight crew will be able to see directly through the IVU to the critical instruments [13]. The set-up of the IVU is displayed in Figures 5-7 below.



Figure 5: IVU removed from container and placed in front of Captain [12]



Figure 6: IVU Inflated to view critical flight instruments [12]



Figure 7: Pilots using IVU [12]

The IVU, as shown in the above figures only covers the primary flight instruments but does not cover engine instruments and controls, electronic panels and controls, overhead panels, or circuit breakers [13]. This could be problematic for the Captain, as the instruments that may display indications of what is causing the smoke, still can not be seen. Furthermore, any attempt to stop a fire or smoke by turning off the engine controls, electronic controls, or circuit breakers would also not be able to be done due to the IVU not providing visibility paths to those areas of the flight deck and the bulkiness of the IVU limiting the flight crews ability to maneuver around the flight deck. Further downfall of the unit is that the IVU takes 30 to 60 seconds to inflate, which is in addition to the time it takes the flight crew to locate the unit and set it up. In that time frame, the flight deck may have filled with dangerous levels of the smoke while the crew waited upwards of a minute for the IVU to inflate. Once inflated, the IVU also does not form

any air tight seal to the instruments or the flight crew. Therefore, smoke can still get between the IVU and the instruments or the IVU and the flight crews goggles/mask. This may still obstruct their vision, defeating the intent of the IVU. According to the manufacturer of the Emergency Vision Assurance System (EVAS), VisionSafe, their list of customers shows no major US airline having equipped their aircraft with EVAS [14].

In the event of smoke in the aircraft, commercial airlines will follow their Quick Reference Handbook (QRH) for aircraft manufacturer approved procedures to attempt to remove smoke. For example, the 737-800 QRH procedure (Appendix A), instructs the flight crew to descend to below 14,000 feet and open the outflow valve. This will depressurize the aircraft in an attempt to draw smoke out through the cabin – this is essentially a “crude” Negative Pressure Smoke removal system in place today. In a worst case scenario, the QRH authorizes the First Officer to open their window while cautioning the effects of opening the window, such as noise levels [15]. This procedure too has its downfalls, as first off it takes time to descend from upwards of 35,000ft to 40,000ft down to 14,000ft in a safe manner. Then the aircraft is depressurized to try and rid the aircraft of smoke. Depressurization may cause aircraft structure issues and passenger discomfort. Lastly, the procedure says to open a window, which the procedure cautions about doing. This in itself could pose a danger to the flight crew with noise.

The QRH is however an accepted and practiced procedure by airlines. The FAA released Advisory Circular (AC) 25-9A in 1994 for test procedures related to smoke and fire on the aircraft [16]. This Advisory Circular references Code of Federal Regulation (CFR) Title 14 – Aeronautics and Space, Part 25.831 which authorizes the use of depressurization to evacuate smoke from the aircraft. This is the regulation that enables a

Negative Pressure System to remove smoke from an aircraft flight deck to be installed on an aircraft.

CHAPTER 3

METHODOLOGY

With smoke and fume related incidents of nearly 900 being reported and the Emergency Vision Assurance System (EVAS) currently the only marketed smoke displacement system, there is a need for a viable flight deck smoke removal system [6],[14]. With the regulations stating that the aircraft can be depressurized in an attempt to remove smoke from the aircraft, a Negative Pressure System could be that viable option [16].

The Negative Pressure System would expand on the existing Smoke Removal Procedure of the Quick Reference Handbook (QRH) which allows for the opening of the aircrafts pressurization control outflow valve at 14,000 feet [15]. This Negative Pressure Control System would however enable the flight crew to safely evacuate the smoke from the flight deck in a controlled manner while maintaining altitude.

What enables this is having a separate, isolated system from the current pressurization system found on most commercial aircraft today. A schematic of an aircraft's pressurization system is depicted in Figure 8 where it shows the location of the outflow valve at the aft end of the aircraft and the engine bleed system that provides the air to the Air-Conditioning Packs, which pressurizes the cabin [17]. Figure 9 shows the areas of the aircraft which are pressurized and the relation of the outflow valve to the flight deck. If the outflow valve were to be opened to evacuate smoke from the flight deck, the smoke would have to pass through the entire cabin area and the aircraft would have to completely depressurize which would be inefficient.

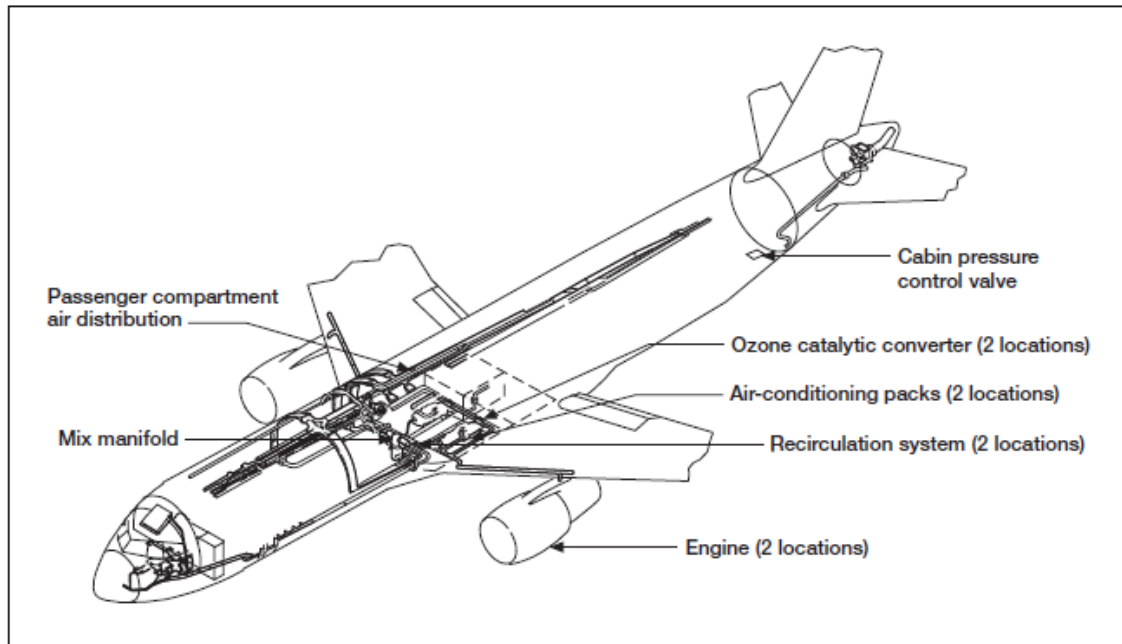


Figure 8: Typical Aircraft Pressurization System Schematic [17]

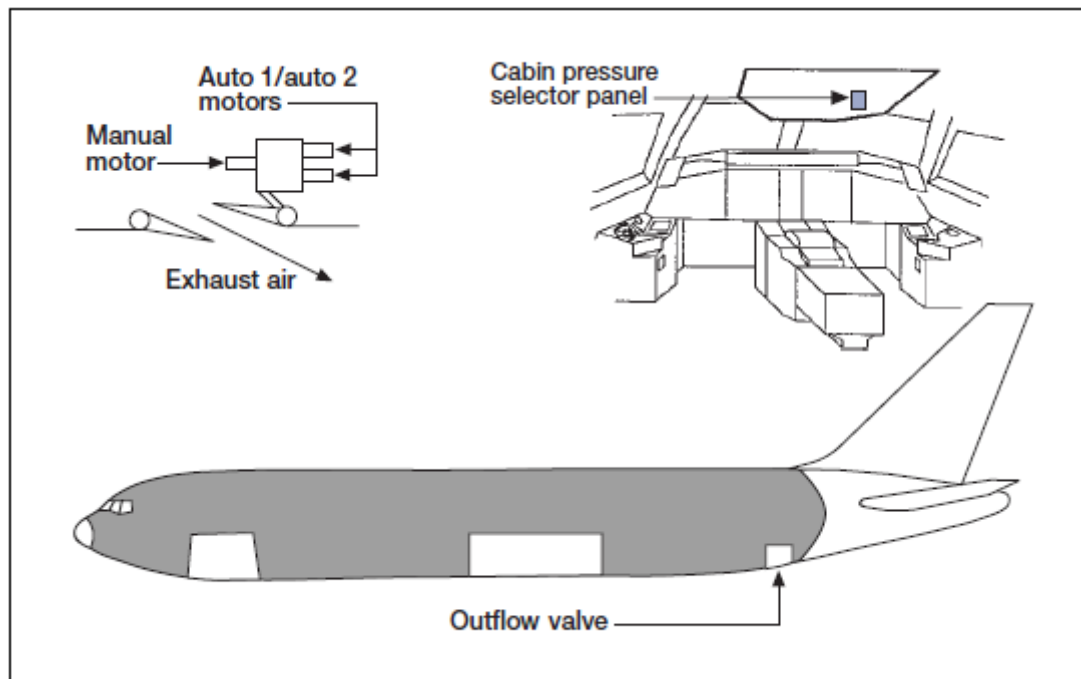


Figure 9: Aircraft Pressurized Areas [17]

The Negative Pressure System for Flight Deck Smoke Removal will be an automatic system, with manual overrides that will consist of a two valve system per side, Captain and First Officer, a smoke detector system, a pressure sensor, an exhaust valve, a filter system, and all items will be contained within a chamber.

The first component of the system is the smoke detection. A smoke detector, such as an Aspirating Smoke Detector (ASD), would be used. The ASD uses an aspirating fan to draw air through sampling pipes to detect smoke. This type of smoke detector provides a higher than normal sensitivity allowing for earlier detection [18]. With the ASD, the sampling pipes could be located in various places of a flight deck that smoke may originate from which may provide earlier detection than a standard detector. The smoke detection system would be tied into the aircrafts computer system. When the smoke is sensed, the valve system for smoke removal will be triggered to operate

The valves for the system will be similar to that of the outflow valve already found on pressurized aircraft. There will be two valves per side of the flight deck, the Captains side and the First Officers side of the aircraft. The system will be identical for both sides. The system will have one set of valves that will be located within the pressurized area of the flight deck and the second set of valves on the fuselage. Each valve will be connected by a duct/chamber area. Both sets of valves will be normally closed. Therefore, when the aircraft pressurizes, the chamber area connected by the valves will be isolated and thus unpressurized. When the smoke detection system triggers the valve system, the valve in the flight deck will open and the differential pressure between the flight deck and the chamber will cause the smoke to be drawn through vents into the chamber. Aircraft typically fly with a cabin pressure to outside

pressure differential of about 8 PSI. As the aircraft altitude increases, the cabin altitude increases, as shown in Figure 10, all the while maintaining the differential pressure of about 8 PSI [17].

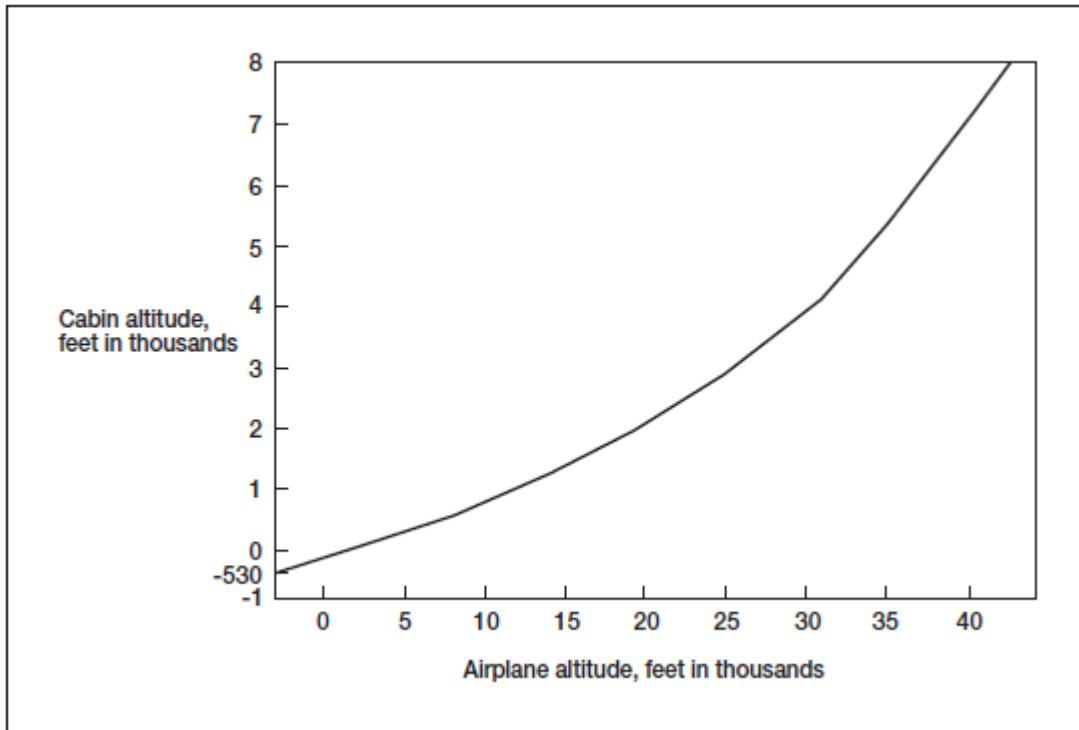


Figure 10: Cabin Altitude vs. Airplane Altitude [17]

The pressurization system of the aircraft through the opening and closing action of the outflow valve will keep pressure changes to between 0.16PSI and 0.26PSI per minute while the aircraft descends or ascends [17]. When the valves in the negative pressure smoke system are activated, this is counteracting the work of the outflow valve by causing sudden changes in cabin altitude. This is due to the opening of the first valve to the chamber has increased the volume of the pressurized area of the aircraft by the now pressurized volume of the chamber. This is addressed by having a pressure sensor system in the chamber linked to the pressurization system of the aircraft.

When the first valve is opened to allow smoke to flow into the chamber, the pressure sensors will determine the pressure between the chamber and the cabin. As the pressure normalizes, the valve will shut. This will prevent the smoke from reentering the flight deck. This will however likely cause an increase in cabin pressure altitude. For example, Figure 10 shows a cabin altitude of about 8,000 feet when the aircraft is cruising at 40,000 feet; by opening the valve to the smoke chamber, the cabin altitude will raise. Though 8,000 feet is a comfortable level for passengers, Federal Aviation Regulation (FAR) 91.211 does not require supplemental oxygen when the cabin pressure altitude is below 12,500 feet [19]. Therefore, the pressure sensors would effectively maintain safe cabin pressures but enough of a pressure differential between the cabin and the chamber to draw smoke in. This is what allows for smoke removal process to begin at cruise altitudes.

Once the pressure between the cabin and the chamber has normalized, the smoke will be vented overboard by the opening of the second valve located on the exterior of the fuselage. Similar to the way the smoke entered the chamber, the chamber is now pressurized and at that 8PSI differential to the outside, thus the smoke will be vented overboard. The placement of the exterior valve is however critical as to be above the plane line of the engines. As smoke exits the aircraft, if it is not properly routed, it may enter into the engines bleed air system and routed back into the aircraft cabin.

In an effort to maintain a safe aircraft cabin pressure altitude, the valve system, identical on the Captain side and First Officers side, would alternate. That is, once the system has been activated, the Captain's side would first open the valve to draw smoke into the chamber. Once the Captain's first stage of the smoke removal cycle completes

with the valve in the flight deck closing and the second valve opening, the First Officer's side will begin with the valve in the flight deck opening. Thus, no two valves are open at the same time but both sides are being utilized for sufficient smoke removal.

The system is automatic and will continue to cycle open and closed until no smoke is detected or the flight crew has determined an issue and manually stops the cycling of the system; which will reset the system and will automatically start again at the next detection of smoke.

In the manner the flight crew can manually stop the cycling the system, the system would also have a manual switch where a manual activation of the system will cycle the system. Since this is a manual operation of the system, the pressure sensors would cycle the valves sooner, as to not have as great of effect on the aircrafts cabin altitude pressure.

A flight crew may want to manually operate the system for two reasons; one, if smoke can be seen but the smoke detection system has had a failure and two, if there is an odor present but no smoke. Since the bleed air from the engines provides air to the air-conditioning PACK which is then recirculated for 50% fresh and 50% recirculated, Cabin Air Quality (CAQ) has been an issue [17]. This manual activation will expel the odor from the flight deck and the flight crew can then determine if it was an isolated event or if the odor persists.

In the event the flight crew operated the system manually for odor, or even if it was operated due to smoke, the system will have a filter element downstream of the first valve contained within the chamber. These filters then can be removed for analysis using such equipment as an Energy-Dispersive Spectrometer (EDS) for Scanning Electron

Microscope (SEM) Analysis [20]. Such an analysis can determine what the composition of material was collected on the filter so an aircraft maintenance team can determine where the odor and/or smoke may have originated from.

The final part of the system is an exhaust fan within the chamber. This fan will aid in drawing smoke into the chamber which would be beneficial if the aircraft is at low altitudes. If the aircraft is at low altitudes, the aircraft may not be pressurized meaning the outflow valve for pressurizing the aircraft is open. However, since the aircraft is unpressurized, there is no pressure differential to draw the smoke through the outflow valve. The exhaust fan will provide the necessary means to remove any smoke from the flight deck.

A layout of the Negative Pressure System is in Figure 11 below.

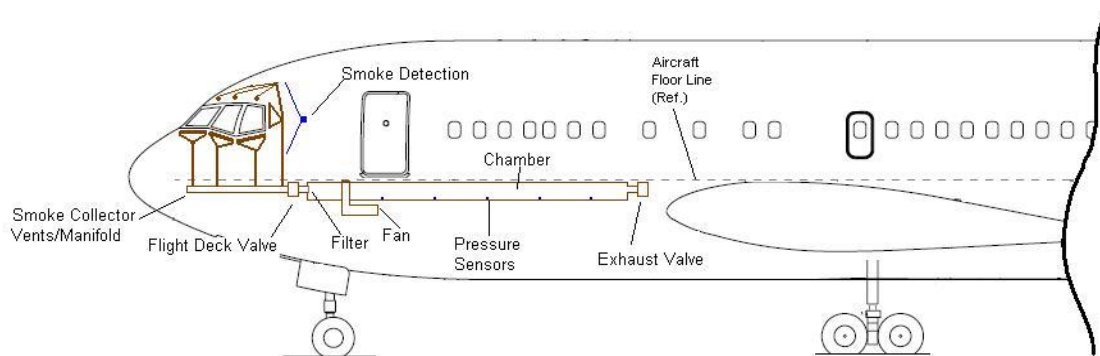


Figure 11: Negative Pressure System layout

CHAPTER 4

RESULTS

The use of a Negative Pressure System for Flight Deck Smoke Removal results in the time saved for a flight crew to safely determine an issue with the aircraft prior to descending. The significance of being able to remove the smoke at an altitude such as 35,000 feet as opposed to 14,000 feet is the significant amount of time a flight crew can save to react and troubleshoot. From the FAA Advisory Circular 61-107A, an aircraft cabin pressure would descend about 500 Feet Per Minute to prevent inner ear problems for passengers and crew; this equates to about 14 minutes with cabin altitude at 8,000ft when the aircraft is at 35,000ft and a cabin altitude of 1,000ft when the aircraft is at an altitude of 14,000 feet [17], [21]. That 14 minutes of descend time could be critical if there is a lack of oxygen due to the smoke and flight crews cannot react quickly enough to install their oxygen masks. Table 1 shows data from the FAA Advisory Circular the time of useful consciousness, which is the time the flight crew can effectively perform tasks without oxygen.

Altitude (Feet)	Time of Useful Consciousness
18,000	10 to 15 minutes
22,000	5 minutes
25,000	1.5 to 3.5 minutes
28,000	1.25 to 1.5 minutes
30,000	30 to 60 seconds
35,000	15 to 30 seconds
40,000	7 to 10 seconds
43,000	5 seconds
50,000	5 seconds

Table 1: Time of Useful Consciousness vs. Altitude [21]

Since there is only a matter of seconds to react to an event, it is imperative to have an automatic system to remove smoke. This will provide precious amounts of time for the flight crew to react. What enables this system to work effectively is a result of Boyle's Law. If it is assumed that at an instant in time, the amount of gas in the flight deck is fixed and temperature is constant, the pressure and volume are inversely proportional given in the equation as follows [22]:

$$p_1 V_1 = p_2 V_2$$

The volume, V_2 , would be equal to the volume of the flight deck, V_1 plus the volume of the chamber. Therefore, the equation becomes:

$$p_1 V_1 = p_2 (V_1 + V_{\text{chamber}})$$

This demonstrates that this increase in volume with the chamber will increase the pressure in the flight deck.

Since the design of the system is based on smoke/air moving from the larger area of the flight deck, into the smaller area of the chamber, and finally out into the atmosphere, the design of the system can be modeled with a Venturi Effect. That is, as the smoke passes through the constricted area from the flight deck to the chamber, the pressure decreases and the velocity increases. This effect can be used to calculate Volumetric Flow Rate, Q , as in the following equation [23]:

$$Q = v_1 A_1 = v_2 A_2$$

For this system, A_1 would be the cross-sectional area of the flight deck and A_2 the cross-sectional area of the chamber. Since aircraft flight decks vary in size, A_1 will change based on aircraft type, therefore the system could be designed to meet the needs of a smaller aircraft and thus have a smaller chamber area, A_2 . The flow rate would be

important in estimating the number of times the system would have to cycle to remove the air from the flight deck. The rate at which smoke can effectively be removed from the aircraft will be what determines how viable of a solution this Negative Pressure System is to commercial aircraft.

Though the system may be beneficial, other factors affect the results in the performance of the system. Since the system is based on utilizing the aircrafts pressurization system, the system must do work in order to maintain pressurization. As mentioned in the Methodology section for Figure 8, the engine bleed system provides the air to the air-conditioning pack system. As the aircraft pressurizes, more air is needed to be bled off the engine, resulting in less efficiency.

Another factor that decreases efficiency of the aircraft is weight and balance. The system will require a substantial increase in weight to the aircraft. The weight and balance is calculated by finding a moment of the added weight (in this case, the smoke removal system) in relation to a datum line, which is calculated using the following equation [24]:

$$M = Fd$$

With this system being located in the flight deck, it will be forward of the Center of Gravity, which may alter flight characteristics slightly. The weight will have most effect on fuel, as that is extra weight that will be carried by the aircraft.

Lastly, the system will have a noticeable effect on the aircraft because the second valve will be in the fuselage skin to exhaust overboard. The cutout of the skin is critical; however, the installation of the valve in the placement of the cutout negates the structural effect of the cutout. However, from the Boeing Fuel Conservation – Airframe

Maintenance for Environmental Performance, excrescence drag, which is the drag on the airplane due to deviations from the smooth external surface, can make the aircraft less efficient. A 1% increase in drag on a Boeing 767 for example can increase fuel consumption by 30,000 gallons per year. Boeing states that the forward area of an aircraft's fuselage is a critical area and requires a high degree of aerodynamic smoothness [25]. The second valve to exhaust smoke overboard then becomes critical in its location on the aircraft as to reduce the aerodynamic effect.

The aerodynamic effect of the valve may have a long term economical effect with the cost of fuel for a commercial aircraft. This is in addition to the additional costs that would be involved with the complexities of integrating a new system into the aircraft. The design, testing, implementation, and subsequent maintenance of a Negative Pressure System for Flight Deck Smoke Removal will likely result in a high financial cost.

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

With the significant amount of reports of smoke and fumes being reported in commercial aircraft, there is a need to address this issue. The advancements in aviation technology have seen both its pros and cons. The advanced technology has made flying overall more reliable and more efficient. The drawback however is that pilot skills are dulled by automation and the electronics needed for the automation increases fire potential. This fire potential has led to some recent development in technology that could be beneficial to a flight crew without increasing their work load.

The advantage of having an automatic Negative Pressure System to remove smoke from a flight deck is that the system would be designed in such a way that a pilot would not have to descend to a lower altitude to begin the process of removing smoke from the flight deck. This buys the flight crew precious time to make critical decisions to determine the cause and extent of danger from any smoke. By being able to operate the system at altitude, there is also no need to do an emergency descent to depressurize the cabin. This preserves passenger comfort and prevents any serious effects of rapid decompression on the aircraft structure.

The primary advantage is that this is the only system that would remove smoke from a flight deck whereas others merely disperse the smoke. By being able to successfully remove smoke from the flight deck, it prevents smoke from building up which may prevent a flight crew from viewing critical instruments. In order for a flight crew to maintain safe flight, they need to be able to easily see these critical instruments

and be able to easily access all controls they may need as they make quick decisions on how to handle the emergency.

The disadvantages of the system are going to be that the complete system will have to be incorporated into the aircraft design. This will require additional weight, structural changes, increases in drag, electrical power, and changes to the aircraft computer system so the systems can integrate together. This will come at a high cost and may only be suitable for new production aircraft. Any type of retrofit system to existing aircraft may be cost prohibitive. Therefore, the system would only have a very small market share of the world's aircraft population; thus not making a significant impact.

With no smoke removal technology for commercial aircraft available, only smoke displacement, it is recommended to further study how smoke can effectively be removed from an aircraft. It is recommended to investigate all aircraft types as designing a system around one aircraft type may not be practical due to the variations in aircraft size and the performance of the aircraft – which could affect cabin altitude pressure and the altitude it cruises at. Though the number of catastrophic accidents due to smoke in the flight deck are relatively low; the growth of aircraft travel will dictate the need for a system such as the Negative Pressure System to Remove Smoke from an Aircraft Flight Deck.

REFERENCES

- [1] Joan Lowy. (2011, August) AP IMPACT: Automation in the Air Dulls Pilot Skill. [Online]. <http://www.deseretnews.com/article/700174876/AP-IMPACT-Automation-in-the-air-dulls-pilot-skill.html>
- [2] Morton, J. (2001, April). Flight and Cabin Crew Response to In-flight Smoke. *Boeing Aero.* 3-10.
- [3] National Transportation Safety Board. (2012, November). *Improve Fire Safety in Transportation*. [Online]. http://www.nts.gov/safety/mw14_2012.html
- [4] Federal Aviation Administration. (2012, March). *FAA Aerospace Forecast Fiscal Years 2012 – 2023*. [Online]. http://www.faa.gov/about/office_org/headquarters_offices/apl/aviation_forecasts/aerospace_forecasts/2012-2032/
- [5] Topham, J. (2013, January). *Boeing Dreamliners Grounded Worldwide on Battery Checks*. [Online]. <http://www.reuters.com/article/2013/01/17/us-boeing-dreamliner-idUSBRE90F1N820130117>
- [6] Federal Aviation Administration. (2010, October). *InFO 10019 – Information For Operators; Smoke/Fumes in the Cabin/Cockpit of Transport Category Aircraft*. [Online]. http://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/info/
- [7] Boeing. (2011). *Statistical Summary of Commercial Jet Airplane Accidents 1959-2011*. [Online]. <http://www.boeing.com/news/techissues/pdf/statsum.pdf>
- [8] Basusta, U. (2008, November). *UPS Cargo Boeing 747Crashes*. [Online]. <http://www.airnewstimes.co.uk/unal-basusta-ups-cargo-boeing-747-crashes-240-article.html>
- [9] National Transportation Safety Board. (2011, September). *Safety Recommendation A-11-87-91*. [Online]. <http://www.nts.gov/doclib/reclatters/2011/a-11-087-091.pdf>
- [10] National Fire Protection Association. (2013, January). *The Consequences of Fire*. [Online]. http://www.nfpa.org/itemDetail.asp?categoryID=1367&itemID=31834&URL=Press%20Room/A%20Reporter%27s%20Guide%20to%20Fire%20and%20the%20NFPA/The%20consequences%20of%20fire&cookie_test=1
- [11] Wynbrandt, J. (2004, August). *Spatial Disorientation – Confusion that Kills*. AOPA Safety Advisor. 1-10.

- [12] RAESE Group. (2012, October). *Smoke Displacement Technology – A Vital Insurance Policy*. [Online]. <http://www.raesegroup.com/2012/10/09/smoke-displacement-technology-a-vital-insurance-policy/>
- [13] Vision Safe. (2009, June). *EVAS Training Outline*. [Online]. <http://www.visionsafe.com/VisionSafe.com/Content/docs/Classroom%20handout%20022713.pdf>
- [14] Vision Safe. (2013, February). *EVAS Equipped Operators*. [Online]. <http://www.visionsafe.com/operators.html>
- [15] Copa Airlines. (2009, October). *B737-700/800 Quick Reference Handbook*. [Online]. <http://cmpva.org/manops/quick%20reference%20manual%20B737-70025.pdf>
- [16] Federal Aviation Administration. (1994, January). *Advisory Circular 25-9A – Smoke Detection, Penetration, Evacuation Tests and Related Flight Manual Emergency Procedures*. [Online]. http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/22464
- [17] Hunt, Elwood., Reid, Don., Space, David., Tilton, Fred. (1995). Commercial Airliner Environmental Control System. *Engineering Aspects of Cabin Air Quality*, 1-8.
- [18] Air Sense Technology. (2013, January). *Aspirating Smoke Detection – A Brief Guide for the Designer*. [Online]. http://www.airsensetechnology.com/documents/guides/brief_guide.pdf
- [19] Federal Aviation Administration. (2012, November). *Code of Federal Regulations – FAR 91.211*. [Online]. http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgFAR.nsf/0/ba9afb96db c56f0852566cf006798f9!OpenDocument
- [20] EDAX Smart Insight. (2011, March). *EDS for SEM Analysis*. [Online]. <http://www.edax.com/Products/EDS/TEAM/TEAM-EDS-SEM-Analysis-Phase-mapping-Spectra-collection.aspx>

- [21] Federal Aviation Administration. (2003, January). *Advisory Circular 61-107A – Operations of Aircraft at Altitudes Above 25,000 Feet MSL and/or MACH Numbers (MMO) Greater than 0.75*. [Online].
http://www.faa.gov/pilots/training/airman_education/media/ac%2061-107a.pdf
- [22] Think Quest. (2013, February). *Boyles Law*. [Online].
<http://library.thinkquest.org/12596/boyles.html>
- [23] Western Washington University Physics Net. (2013, January). *Volumetric Flow Rate*. [Online].
<http://faculty.wwu.edu/vawter/PhysicsNet/Topics/Pressure/VolumeFlowRate.html>
- [24] Federal Aviation Administration (2005, June). *Advisory Circular 120-27E – Aircraft Weight and Balance Control*. [Online].
http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/22749
- [25] International Civil Aviation Organization. (2006, September). *Fuel Conservation Airframe Maintenance for Environmental Performance*. [Online].
<http://www.icao.int/Meetings/EnvironmentalWorkshops/Documents/ICAO-TransportCanada-2006/Anderson.pdf>

APPENDIX A

BOEING 737-700/800 QUICK REFERENCE HANDBOOK (QRH)

SMOKE/FUMES REMOVAL PROCEDURE



SMOKE / FUMES REMOVAL

Oxygen Masks & Regulators

(Smoke Goggles, If Required) ON, 100%

Crew Communications ESTABLISH

Flight Deck Door CLOSED

IF Packs ON And Smoke / Fumes Source Confirmed On Flight Deck Or Main Cabin:

L & R Pack Switches HIGH

Recirculation Fan Switch(s) OFF

Land Altitude TO 10,000 FEET MAX

No. 1 & No. 2 Bleed Air Switches VERIFY ON

Engine Thrust (Max Practical) ABOVE 45% N₁

OR

Flight Deck Air Cond & Gasper Outlets OPEN

Caution: Do not open the flight deck window. Keep the flight deck door closed.

IF Smoke / Fumes Are Uncontrollable:

Aircraft Altitude MEA OR 10,000
FEET, WHICHEVER IS HIGHER

At 14,000 feet or below:

Pressurization Mode Selector MAN

Outflow Valve Switch OPEN

IF Packs OFF And Smoke / Fumes Source Confirmed On Flight Deck:

Airspeed NORMAL HOLDING SPEED

Caution: Window should not be opened unless the source is confirmed to be originating on the flight deck.

Slow aircraft to holding airspeed to minimize the effect of opening a flight deck window.